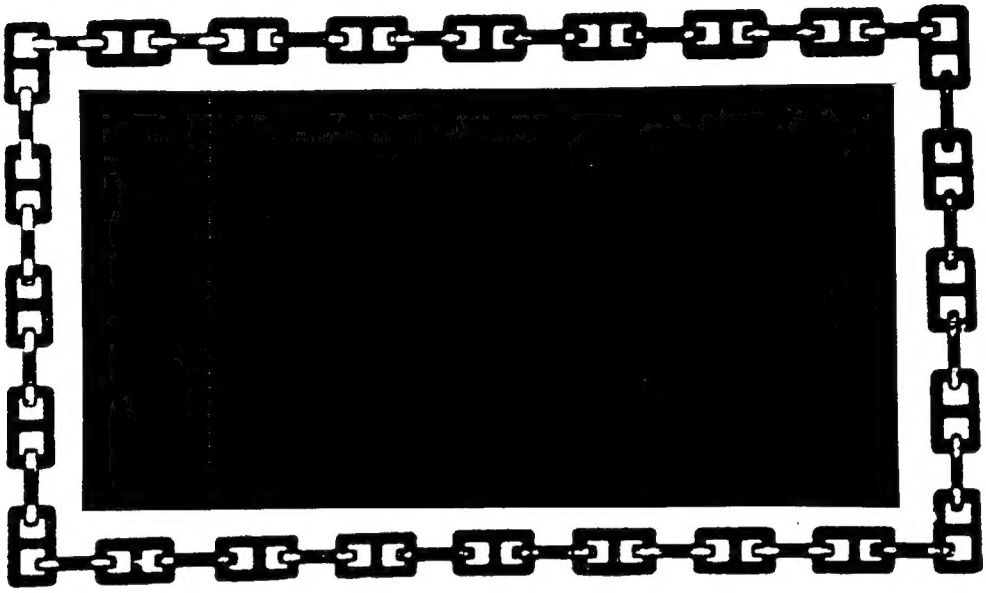

NAVY EXPERIMENTAL DIVING UNIT

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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 1-93

NEUROPSYCHOLOGICAL BATTERY DEVELOPMENT FOR DETECTING CEREBRAL DECOMPRESSION SICKNESS

FEBRUARY 1993

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The feasibility of developing a portable neuropsychological assessment battery for employment throughout the fleet was examined. Neuropsychological performance data were collected from divers assigned permanently to NEDU, as well as TAD divers participating in experimental dives conducted at NEDU. The various tests used for collecting baseline performance scores are discussed. Baseline performance levels are presented, as well as performance levels across repeated test trials. The limitations to developing and administering such a battery in the fleet are also discussed, and some potential alternative test batteries are described.

The tests that were used in this neuropsychological battery assessed: long-term and short-term memory; symbol translation processing speed; affective status; sequence processing speed; word fluency;

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Item 19 continued:

fine motor control; and grip strength. Generally, performance on most measures increased across the first two test administrations and reached a stable level after three administrations, provided the interval between successive administrations was shorter than 240 days.

GLOSSARY

AGE	Arterial Gas Embolism
DCS	Decompression Sickness
GRIP	Grip Strength
HBO	Hyperbaric Oxygen
MAACL	Multiple Affect Adjective Checklist
MAACL-ANX	Multiple Affect Adjective Checklist-Anxiety Scale
MAACL-DEP	Multiple Affect Adjective Checklist-Depression Scale
MAACL-HOS	Multiple Affect Adjective Checklist-Hostility Scale
MAACL-PA	Multiple Affect Adjective Checklist-Positive Affect Scale
MAACL-SS	Multiple Affect Adjective Checklist-Sensation Seeking Scale
NEDU	Navy Experimental Diving Unit
NMRI	Navy Medical Research Institute
PAB	Performance Assessment Battery
RRT	Restricted Reminding Task (Buschke Task)
SDMT	Symbol Digit Modalities Test
TMA	Thurstone Test of Mental Alertness
TMA-L	Thurstone Test of Mental Alertness-Linguistic Scale
TMA-Q	Thurstone Test of Mental Alertness-Quantitative Scale
TRAILS	Trailmaking Task
WMS	Wechsler Memory Scale
WORDFLU	Word Fluency

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

In the course of conducting manned dives, the incidence of decompression sickness (DCS) increases with greater diving depths and longer bottom times. Mild (Type I) DCS symptoms can include joint pain and lymph swelling, as well as marbling of the skin (*cutis marmorata*). More severe cerebral (Type II) DCS symptoms include central nervous system (CNS) manifestations, including weakness, paralysis, paresthesia, numbness, extreme fatigue, and dizziness. Divers may also suffer from arterial gas embolism (AGE) due to rupture of alveolar sacs following rapid ascent. Traditionally, when a diver complains of any physical symptoms, he receives a neurological exam to rule out possible CNS involvement.

The neurological exam identifies most divers who have incurred Type II DCS or AGE. However, a patient could conceivably suffer from blood borne bubbles in cerebral circulation, yet still pass the neurological exam. Decompression sickness that selectively affects higher cortical areas may elude detection by the traditional neurological exam because the cognitive and psychomotor manifestations may remain quite subtle.

NAVSEA Task 86-054 directed NEDU to "Devise and validate a portable neuropsychological assessment battery for the diagnosis of cerebral decompression sickness in divers. This screening battery should be amenable to introduction into the NDSTC Diving Medical Officer Course and for use by U.S. Navy Diving Medical Officers in fleet billets."

To prove beneficial as a diagnostic tool in the diving Navy, such an assessment battery would need to: (1) be portable; (2) assess a wide variety of cognitive performance skills; (3) provide stable baseline performance scores; (4) be easy to administer, score, and interpret.

A neuropsychological screening battery was employed at NEDU for this purpose. This battery includes the following tests:

1. Thurstone Test of Mental Alertness (1):

Measures linguistic and quantitative abilities of the subject. The subject has 20 minutes to answer as many questions as he can.

Maximum score: linguistic = 72; quantitative = 54.

2. Symbol Digits Modalities Test (2):

Measures the subject's ability to translate 10 symbols into numerical digits, using a key at the top of the test. Testing is conducted for 90 seconds, and the correct number of translations is recorded.

Maximum score: 110.

3. Multiple Affect Adjective Checklist (State/Today Form) (3):

Measures the current emotional state of the subject along the following three vectors: anxiety, depression, and hostility. New forms of this checklist also measure positive affect and sensation seeking in the subject.

Maximum score: anxiety = 10; depression = 12; hostility = 15.

4. Trail Making Test(4):

Measures the subject's ability to sequentially trace among numbered points (Form A), or alternating sequentially between numbered and lettered points (Form B). Subjects are tested individually; time (in seconds) needed to complete the task is recorded, as are the number of errors made.

5. Finger Tapping:

Measures fine motor control. Subjects are alternately tested three times each using their dominant and nondominant hand for one minute per trial; the average tapping rate for each hand is recorded.

6. Grip Strength:

Accurately measures strength of grip. Subjects are alternately tested three times each using their dominant and nondominant hand; the average grip strength for each hand is recorded.

7. Wechsler Memory Scale Form I (5):

Measures the subject's ability to recall personal and current information (Part I), orientation in time and space (Part II), mental control (Part III), ability to recall a story passage (Part IV), and ability to recite strings of digits forward and backward (Part V).

Maximum score: Part I=6; Part II=5; Part III=9; Part IV=23; Part V=15.

8. Word Fluency:

Measures the subject's ability to recall words that begin with a specified letter in one minute. Subjects are tested with three different letters, and the number of words recalled beginning with each letter is recorded.

II. METHODS

Component tests of the battery were administered to a total of 265 healthy subjects (262 male, 3 female) either assigned to NEDU or TAD divers assigned from NMRI and other dive commands, between November 1983 and June 1990. Most of the tests were administered to divers before they participated in experimental dives, while the remainder of these assessments were conducted following a dive. The Thurstone Test of Mental Alertness, Symbol Digit Modalities Test and the Multiple Affect Adjective Checklist were administered to groups of 5-35 divers, while the remaining tests were individually administered by trained NEDU personnel. Not all tests were administered each time the assessment battery was administered, so for statistical purposes, baseline means were calculated from scores obtained the first time a particular test was administered to an individual.

Additionally, the influence of administering repeatedly the same tests on performance was investigated by comparing test scores across three repeated assessment trials. Such comparisons included data obtained from assessments conducted under baseline conditions, where eight months or less had elapsed between each assessment administration. Data from the following tests possessed a sufficient number of subjects who met these criteria for statistical analysis: Thurstone Test of Mental Alertness; Symbol Digits Modalities Test; Trail Making; Finger Tapping; and Grip Strength. Data from each test were analyzed using a one-way repeated-measures analysis of variance (ANOVA); post-hoc Scheffe pairwise comparisons were conducted when reliable main effects were revealed. For statistical purposes, the significance criterion for data analysis was set at $p<.05$.

III. RESULTS

Baseline performance data are summarized in Table 1. Two demographic variables, age and education, are also included in the table. Data from the Multiple Affect Adjective Checklist are not included, since divers almost uniformly rated each emotional vector at or near zero.

The influence of repeated testing on performance levels is graphically depicted in Figures 1-5. Performance on the Thurstone Test of Mental Alertness (Figures 1a and 1b) increased reliably across repeated trials. This was true both for the linguistic scale and the quantitative scale. In both cases, test performance was reliably higher during the second and third trials, compared to the first trial. There was no difference between the second and third trial scores on either scale.

Performance on the Symbol Digits Modalities Test (Figure 2) also increased reliably across repeated trials. Test performance was reliably higher during the third trial, compared to the first and second trials. There was no difference between the first and second trial scores.

TABLE 1

BASELINE NEUROPSYCHOLOGICAL ASSESSMENT
BATTERY PERFORMANCE LEVELS

MEASURE	MEAN	SEM	N
AGE (YEARS)	27.8	.38	261
EDUCATION (YEARS)	13.4	.14	253
THURSTONE TEST OF MENTAL ALERTNESS			
LINGUISTIC	37.5	.69	223
QUANTITATIVE	27.7	.51	223
TRAIL MAKING (SECONDS)			
FORM A	23.3	.47	255
FORM B	54.1	1.17	256
FINGER TAPPING			
DOMINANT	55.0	.44	197
NON-DOMINANT	49.5	.38	197
GRIP STRENGTH (KILOGRAMS)			
DOMINANT	56.9	.70	251
NON-DOMINANT	54.0	.68	251
SYMBOL DIGIT MODALITIES	56.8	.58	257
WECHSLER MEMORY SCALE			
PART I	4.8	.06	153
PART II	5.0	.00	169
PART III	7.9	.09	169
PART IV	11.0	.21	169
PART V	12.0	.14	168
WORD FLUENCY TEST	16.6	.34	170

Figure 1a. Thurstone Test of Mental Alertness--Linguistic Scale

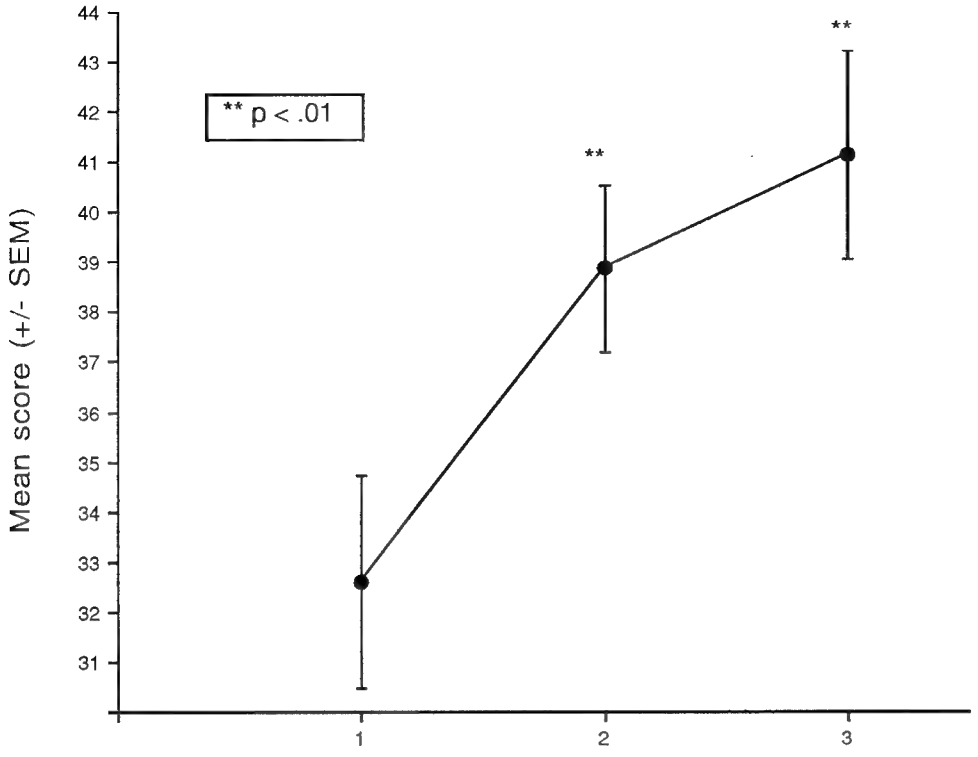


Figure 1b. Thurstone Test of Mental Alertness--Quantitative Scale

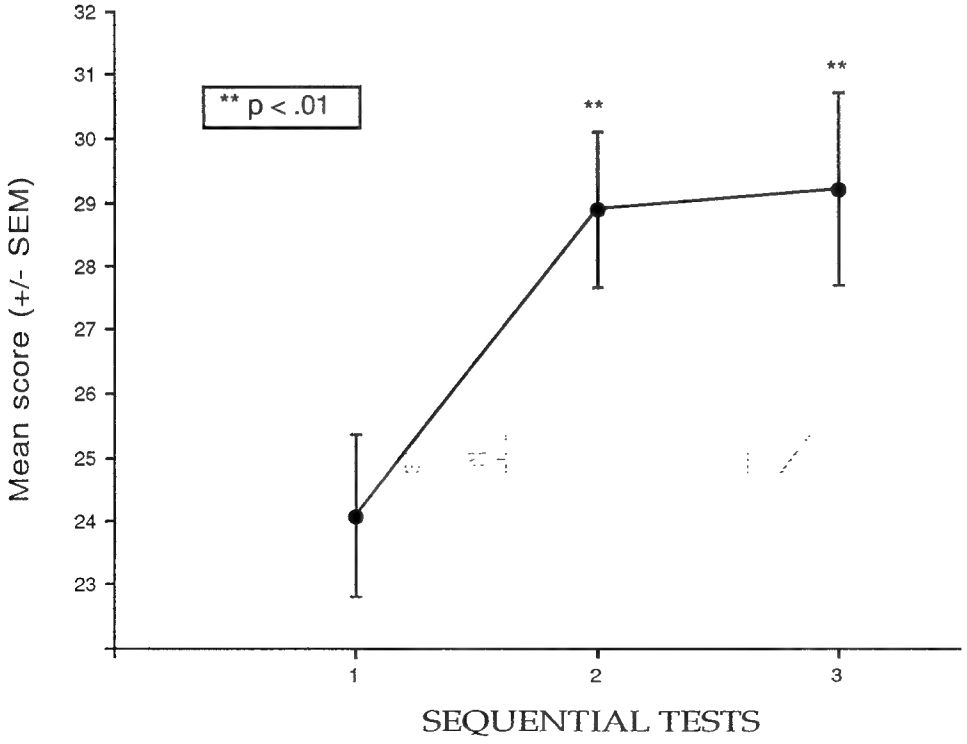


Figure 2. Symbol Digit Modalities Test

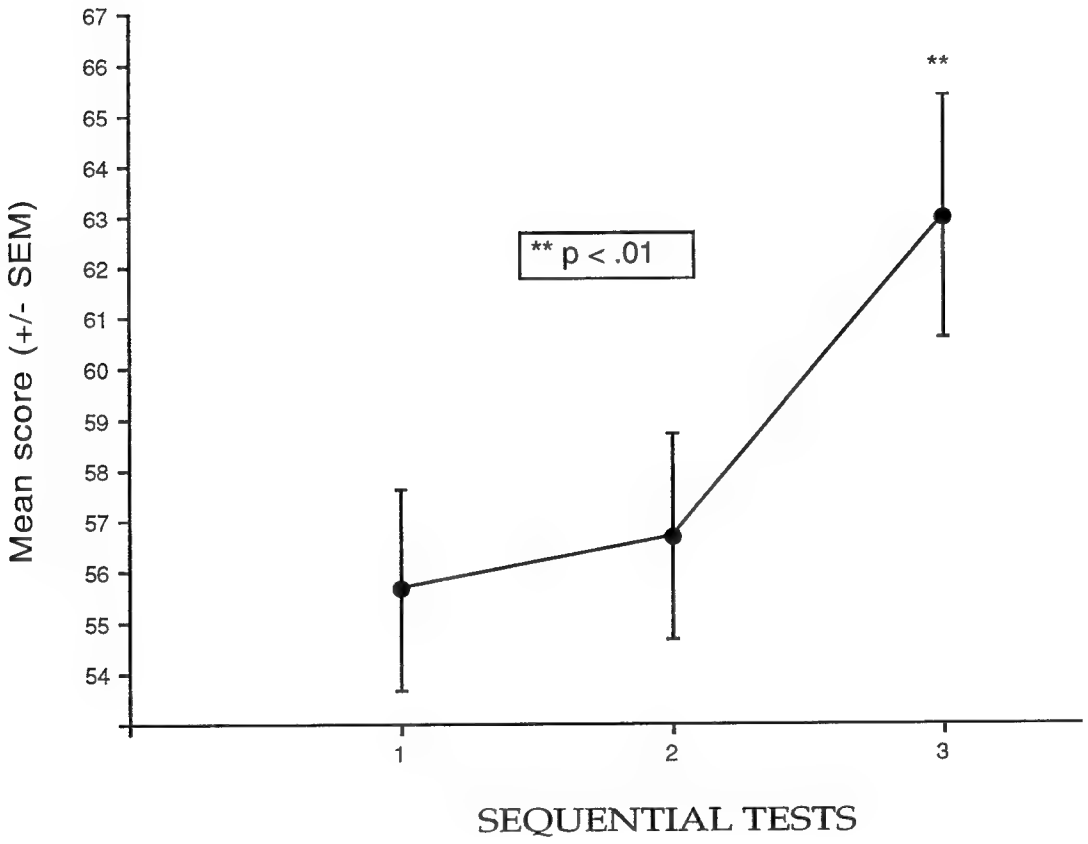


Figure 3a. Trail Making Form A

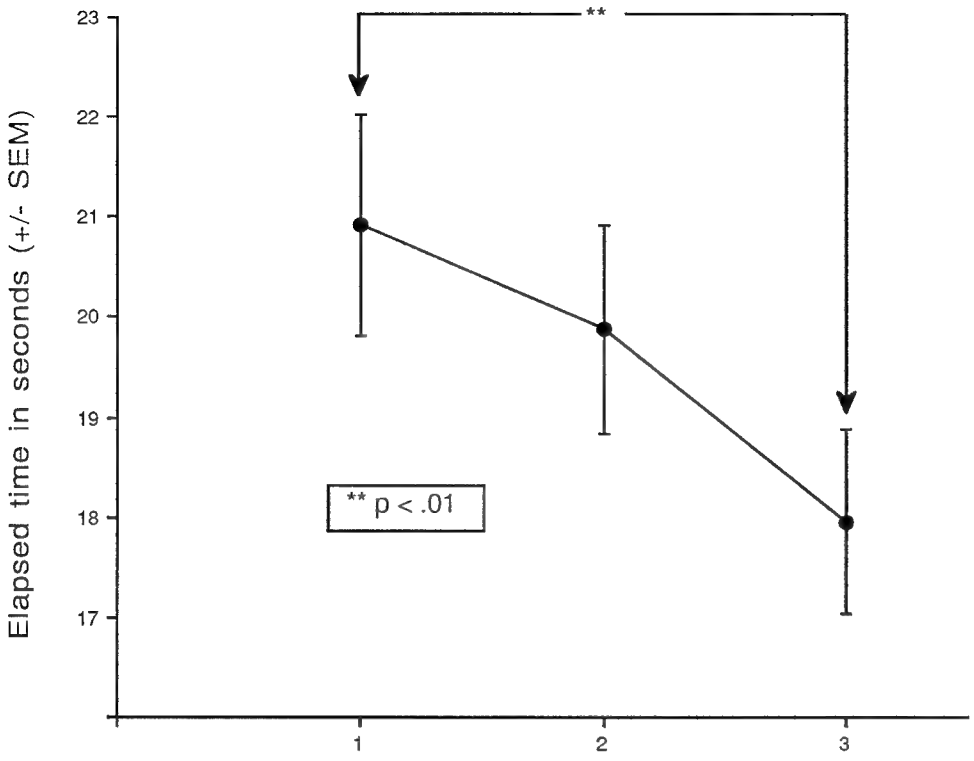


Figure 3b. Trail Making Form B

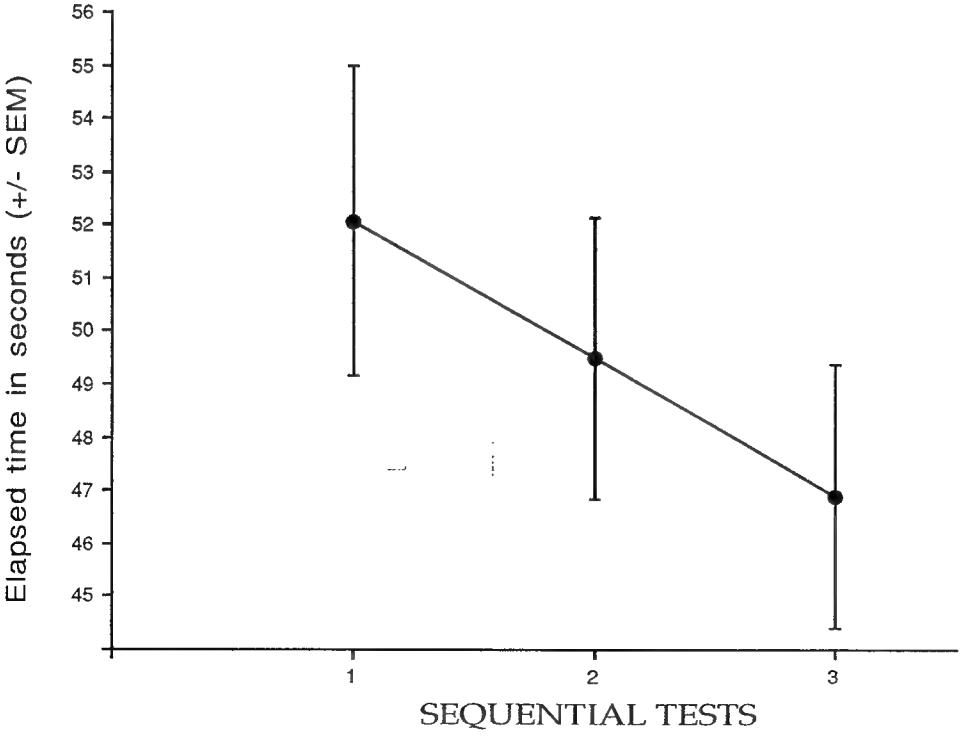


Figure 4a. Dominant Hand Finger Tapping

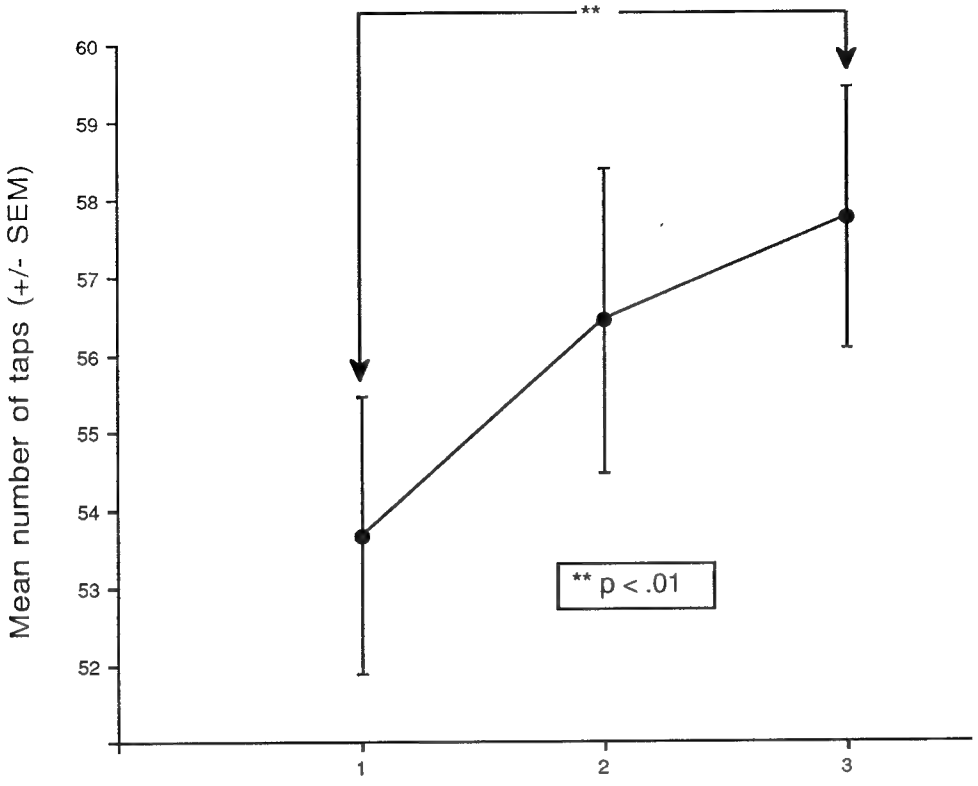


Figure 4b. Non Dominant Hand Finger Tapping

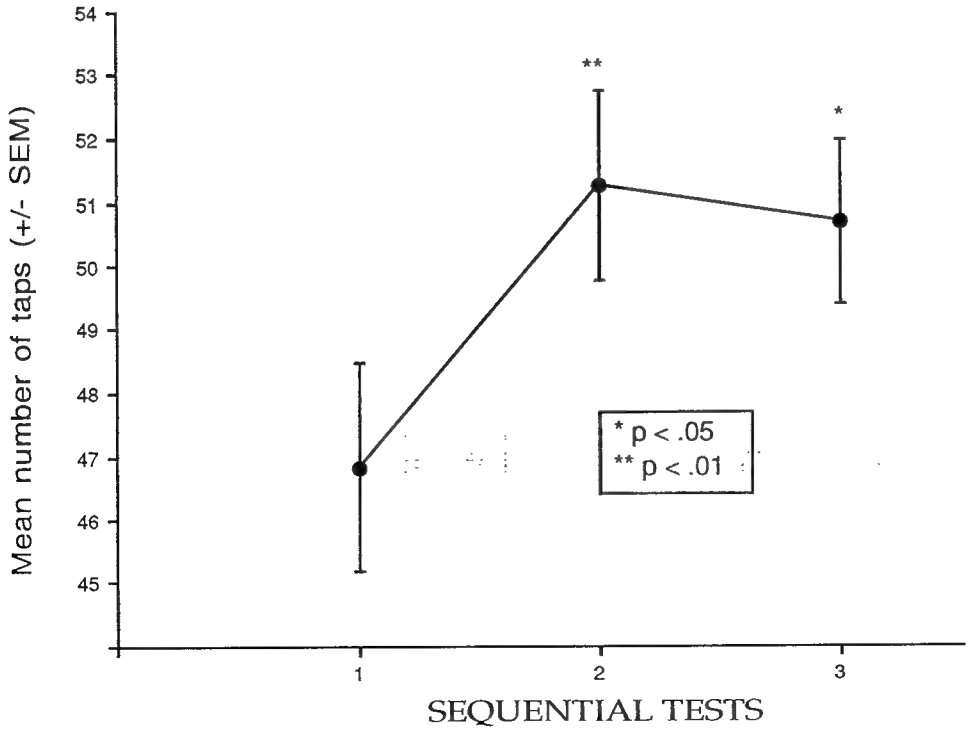


Figure 5a. Dominant Hand Grip Strength

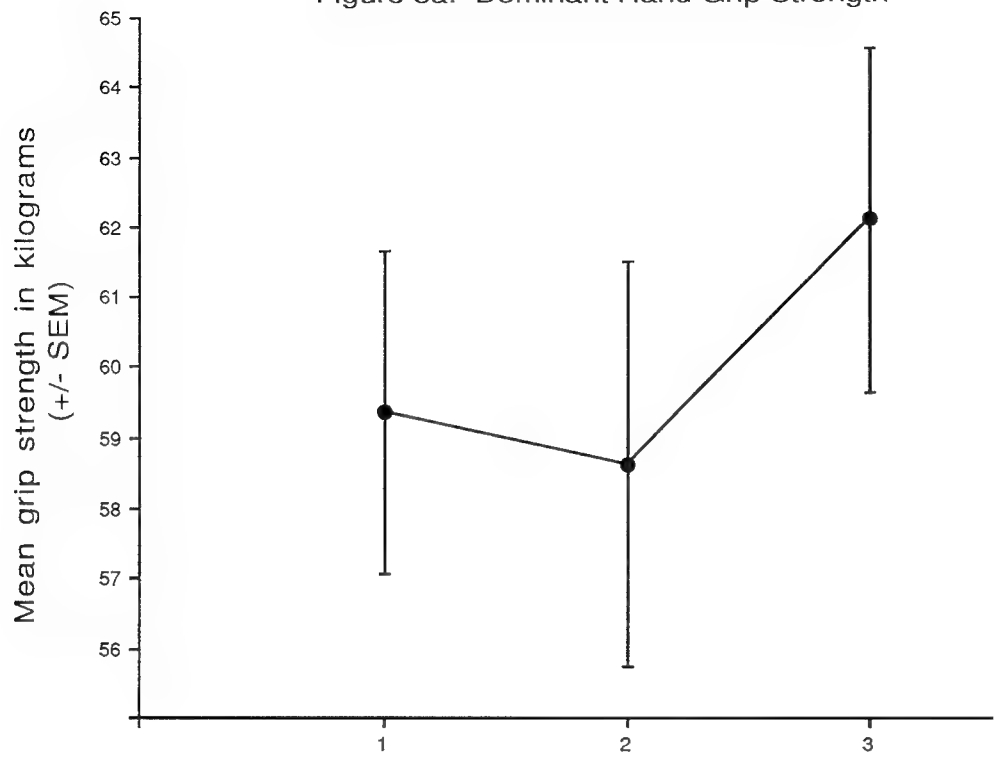
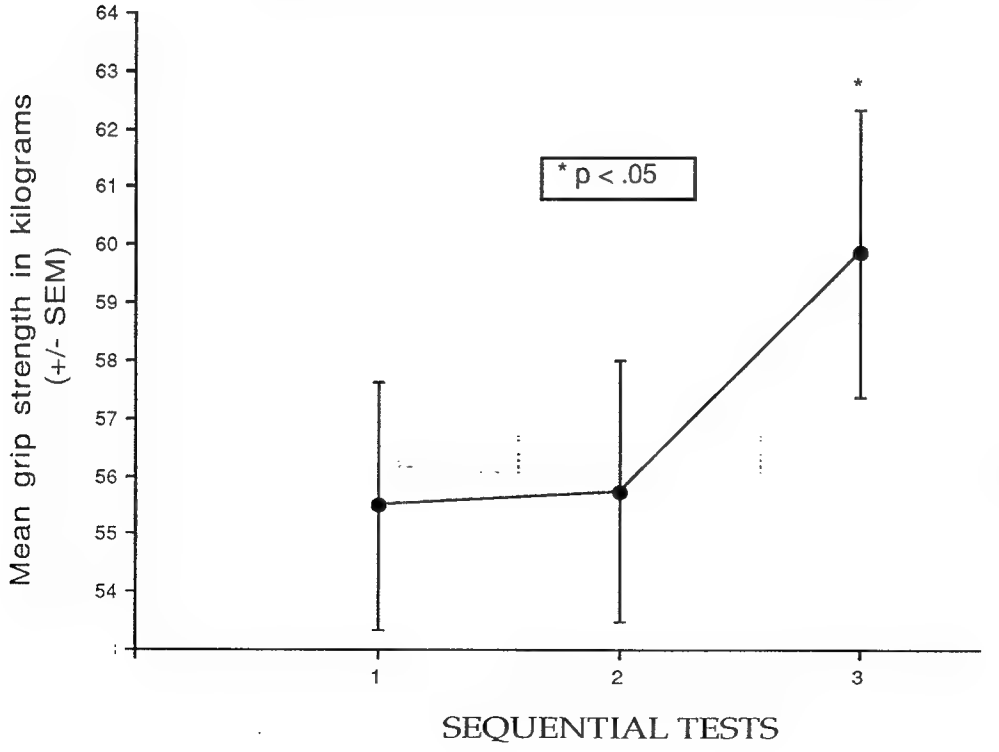


Figure 5b. Non Dominant Hand Grip Strength



Performance on Form A of the Trail Making test (Figure 3a) became reliably faster across repeated trials. Test performance was reliably faster during the third trial, compared to the first. Performance during the second trial did not differ from either of the other trials. Performance on Form B of the Trail Making test (Figure 3b) did not change reliably across trials, although there was a trend for faster performance during the third trial.

Performance on the Finger Tapping test (Figures 4a & 4b) by the dominant hand increased reliably across trials. Performance was reliably higher during the third trial, compared to the first trial. Performance during the second trial did not differ from either of the other trials. Performance by the nondominant hand also increased reliably across trials. Performance was reliably lower during the first trial, compared to second and third trial levels. There was no difference between the second and third trial levels.

Performance on the Grip Strength test (Figures 5a & 5b) by the dominant hand did not change reliably across trials. However, nondominant hand grip strength increased reliably across trials. Performance was reliably higher during the third trial, compared to first and second trial levels. There was no difference between the first and second trial levels.

An additional analysis was conducted to determine whether the length of time between successive trials influenced subsequent test performance, compared to performance on the preceding trial. The data employed in this analysis included all cases where tests were administered to the same subject at least four times, disregarding the length of time between trials. Differences between successive scores were calculated, as were the intervals (in days) between successive trials. Simple regression analyses were then performed to determine whether inter-trial interval length reliably predicted difference scores.

The scores on the quantitative scale of the Thurstone Test of Mental Alertness dropped reliably as a function of longer intervals. This was found between the first and second trials, as well as between the third and fourth trials. Generally, score performance

decreased more following longer inter-trial intervals. An examination of the scattergrams indicated that trials with extremely long inter-trial intervals, i.e., greater than 240 days, tended to produce substantially lower scores, compared to earlier trials. Subsequently, these regression analyses were repeated, but inter-trial intervals exceeding 240 days were excluded from the analysis. No reliable results were revealed from this analysis. All other regression analyses of other battery tests failed to reveal a reliable association between inter-trial interval and difference scores.

IV. CONCLUSIONS/RECOMMENDATIONS

The data included in this report provide baseline cognitive and motor performance levels obtained from healthy U.S. Navy Divers taking this battery for the first time, which may be employed in the future as a reference statistic. Because only a small sample of test subjects have taken the tests more than three times within a reasonably short time period, it remains unclear whether performance can be expected to remain stable during subsequent administrations. Making definitive conclusions about the influence of multiple trials on performance is beyond the data at hand.

These data also suggest that increased performance levels will not accrue from subsequent test administrations if the inter-test interval between successive administrations is longer than 240 days.

Finally, we can not recommend employing this neuropsychological battery for identifying cerebral decompression sickness during operational dives in the Fleet, for several reasons. First, administration of these tests requires trained personnel throughout the Fleet. Second, test scores obtained from a Fleet diver may lack comparison performance scores, since the only valid baseline neuropsychological scores available are those obtained from U.S. Navy divers that have been recently assessed with the battery. Third, there are only two diving psychologists presently available for consultation and test interpretation. Fourth, because the probability of encountering cerebral DCS without other DCS symptoms is unknown, the opportunity to employ such a battery is uncertain under non-research settings. Fifth, an operational setting would not be amenable to conducting traditional neuropsychological tests on a diver with suspected cerebral DCS,

due to the conservative standard for administering HBO treatment. Routinely, a diver who presents with any somatic or CNS complaint immediately receives HBO therapy.

This task is therefore being closed, having accomplished the collection of baseline data using one assessment battery. However, validation and reliability studies would be needed to assess its utility, and these are currently logistically impossible.

Nonetheless, we also believe that a comprehensive neuropsychological assessment that could detect subtle deficits in cognitive performance would be of value for determining whether residual symptoms exist among divers who have received HBO treatment for DCS. These tests would prove valuable in those cases where obvious symptoms of DCS are readily relieved by initial HBO therapy, whereas more subtle cognitive deficits persist. In this case, additional HBO treatments would be indicated, and repeated neuropsychological test trials would be the tool employed to characterize recovery.

Such a scenario would only be tenable if baseline performance data from the diver being treated were already on file. Although it is clearly unrealistic to try to obtain baseline performance statistics on all Fleet divers, it would be a relatively simple matter to administer a neuropsychological assessment battery every six months to all divers stationed at NEDU, as well as the Naval Medical Research Institute and the Naval Submarine Medical Research Laboratory. It would then be possible to employ a standard neuropsychological battery in conjunction with a neurological examination to a diver from one of these commands following recompression treatment, which could provide the most comprehensive evaluation of treatment efficacy.

Three other neuropsychological performance assessment tools are described in Appendix B. The first test is a computer-driven battery, while the other two are paper-and-pencil form tests. Clearly, it would be easiest to standardize the administration of the first of these batteries to divers at the three dive commands for purposes of developing a baseline database, in the hope of revealing subtle cognitive deficits caused by DCS that persist following recompression therapy.

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APPENDIX A

Other Neuropsychological Tests Currently Being
Considered for Evaluation by NEDU

1. The Walter Reed Army Institute of Research Performance Assessment Battery (WRAIR PAB). Generously provided to NEDU by Dr. David Thorne at WRAIR, the PAB is computerized battery that can include up to 20 different tasks that assess affective, perceptual, memory, cognitive, and psychomotor status. The system operates on a custom computer software program for test battery assembly, administration, and scoring. The entire program is run by a personal computer. The subject receives visual stimuli via a color monitor, and his responses are recorded using a standard computer keyboard mounted on the pedal ergometer frame.

Some advantages provided by the PAB over our currently utilized assessment battery include: (1) the PAB is computer generated and administered, eliminating the need for paper and pencil forms traditionally employed; (2) the PAB can include any combination of the tests included in the battery; (3) the tests selected can be presented in any order; (4) stimulus presentation is randomized, eliminating long-term memory influences on performance, so that a subject's performance asymptotes after a few trials; (5) data collection is automatic; and (6) the tests included in the PAB assess all of the cognitive and psychomotor abilities measured by the traditional paper and pencil tests, except for declarative memory measured by the Thurstone Test of Mental Alertness. In addition, the PAB assesses cognitive and psychomotor capacities not provided by our current neuropsychological test battery. The individual tests are listed below, along with a brief description of each (excerpted in part from [6]).

a. Two-letter search: A visual search and recognition task. Two target letters are presented at the top of the screen, along with a string of 20 letters in the middle of the screen. The subject determines as quickly as possible whether both target letters are present in the string (10 trials).

b. Six-letter search: As above, but with six letters instead of two (10 trials).

c. Encoding/Decoding: The subject is presented with a string of nine letters corresponding to digits 1-9. Repeated presentations of the same sequence during repeated trials within a single session measure acquisition speed. A different sequence is employed during successive sessions.

d. Delayed Recall: Administered at the end of a session, tests the subject's memory of the Encoding/Decoding sequence employed during that session.

e. Two-column addition: A subject-paced mental arithmetic task. Five two-digit numbers are presented in a column in the center of the screen. The subject calculates the sum as rapidly as possible and enters it beginning with the hundreds digit. The column of digits disappears with the first key entry, and no aids for the carry operation are allowed (10 trials).

f. Serial add/subtract: A machine-paced mental arithmetic task requiring sustained attention. Two randomly selected digits and either a plus or minus sign are displayed sequentially in the same screen location, followed by a prompt symbol. The subject performs the indicated addition or subtraction and enters the least significant digit of the result (e.g., 8 6 + equals 14, so enter 4). If the result is negative, he subtracts it from ten and enters the positive single digit remainder (e.g., 3 9 - equals -6, so enter 4). The digits and signs are presented for approximately 250 milliseconds, separated by approximately 200 milliseconds (50 trials).

g. Logical Reasoning: An exercise in transformational grammar. The letter pair "A B" or "B A" is presented along with a statement that correctly or incorrectly describes the order of the letters within the pair, e.g., "A follows B," or "A is not preceded by B." The subject indicates whether the statement is true or false (32 trials).

h. Digit recall: A test of short-term memory capacity. Nine random digits are displayed simultaneously in a row across the center of the screen for one second. After a three second blank retention interval, eight of the original nine digits are re-displayed in a different random order, and the subject enters the

missing digit. A given digit may appear no more than twice on each trial, although subjects are not informed of, nor usually aware of this constraint (10 trials).

i. Pattern Recognition I: A spatial memory task. A random pattern of dots (asterisks) is displayed for 1.5 seconds and then followed after a 3.5 second blank retention interval by a second pattern that is either the same or different; the subject decides which and indicates his choice. The pattern consists of 14 dots within an invisible Latin-square matrix where each row and column contains a single dot and 13 blanks (10 trials).

j. Pattern Recognition II: A more difficult version of the above consisting of 16 dots, of which either two or no dots change position (10 trials).

k. Moodscale I: Sixty-five affective adjectives are presented sequentially to the subject. The subject responds to each word using a 5-point scale.

l. Moodscale II: Thirty-six affective adjectives are presented sequentially to the subject. The subject responds to each word using a 3-point scale

m. NIMH: Twenty-five affective statements are presented sequentially to the subject. The subject responds to each statement using a 7-point scale.

n. Wilkinson Serial Reaction Time: The subject is shown a 2 X 2 grid of squares that remains on the screen continuously. One of the squares lights up in red, and the subject responds as quickly as possible by pressing the key on the numeric keypad corresponding to the relative location of the illuminated square, using the 1, 2, 4 and 5 keys (50 trials).

o. Choice Reaction Time: The subject is presented with a single-digit number (0-9) and responds as quickly as possible by pressing the corresponding number key on the numeric keypad (50 trials).

p. Time Wall: The subject sees a "wall" that extends about halfway up the screen. A small square descends from the top of the screen and "behind" the "wall".

The subject's task is to estimate the time that the square would appear in a small square "hole" at the bottom of the "wall" (6 trials).

q. Interval Production: The subject is presented with the image of an analogue clock with a single hand. He presses a key every time he estimates a second has elapsed. Each time the key is pressed, the hand on the clock moves one "second" ahead clockwise. The subject continues to press the key until a full "minute" has elapsed on the clock, i.e., 60 key presses.

r. Stanford Sleepiness Scale: The subject is presented with seven statements about his relative alertness, and chooses the statement that best describes his state at the time.

s. Manikin: A bilateral visual spatial organization task that requires the subject to determine how a male figure has been rotated in space (16 trials).

t. Matching to Sample: The subject is presented with a 5 X 5 grid of red and green blocks. After a brief memorization period, the subject makes a forced choice of two samples simultaneously presented (20 trials).

u. Stroop: Words of different colors are presented to the subject, who has to identify the color of the word. This tests for response competition between perceptual and linguistic identification (48 trials).

2. The Buschke Restricted Reminding Task (RRT): A subject is verbally presented with a list of 20 words that are contextually related (e.g., sports), then recalls as many words as he can in two minutes. He is then reminded only of the words he failed to recall on the first attempt, and he again recalls as many of the words from the entire list that he can. This process is repeated until the subject successfully recalls the entire word list twice in a row, or until he has made eight unsuccessful attempts to do so.

3. The Paced Auditory Serial Addition Task (PASAT): This test was originally developed as a measure of recovery from concussion. The subject is verbally presented with two single-digit numbers, and is instructed to add them and report the sum. He is to remember the second number presented to him, and to disregard

the sum he just reported. Upon hearing the third number, he adds it to the second number he heard, and reports the sum. He again disregards the sum he just reported and, upon hearing the fourth number, adds it to the third number he heard, reports the sum, and so on, until he has been presented with 50 pairs of numbers. Numbers are presented at four increasingly rapid rates, varying from one per 2.4 seconds up to one per 1.2 seconds. Scoring is calculated as the average seconds per correct response.